Effluent Fate Study
Lahaina Wastewater Reclamation Facility
Maui, Hawaii

Final Report

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Prepared for

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Executive Summary

Background

A fluorometric survey of an area of the near coastal waters of western Maui, offshore from the Lahaina Wastewater Reclamation Facility (LWRF) was conducted in August 1993 to determine the fate of the effluent from the LWRF. Effluent is currently injected into four wells drilled to maximum depths of 180-255 ft below the ground surface and located approximately 600 m (2,000 ft) inland from the shoreline. The effluent is assumed to discharge into the near coastal waters. This study was prompted by concerns of suspected causal links between nutrients in the effluent and previous algal blooms reported along the west Maui coastline. The study was conducted at the request of Region 9 of the U.S. Environmental Protection Agency (USEPA) in conjunction with the Environmental Planning Office of the Department of Health of the State of Hawaii, and the Wastewater Reclamation Division of the County of Maui. These agencies are investigating possible land-based hydrologic sources that may be contributing excess nutrient loadings into the coastal waters of western Maui.

The primary objectives of this field study were to investigate the fate of wastewater from the LWRF injection wells, to determine the offshore locations of detectable discharges, and to measure the dispersal of the effluent in the offshore waters. A limited number of water samples from the study area were also collected to characterize the nutrient levels in the vicinity of the LWRF.

In order to achieve these objectives, an artificial tracer was added to the effluent as it flowed into one of four injection wells at the LWRF. The tracer chosen was Rhodamine WT, a fluorescent dye that can be continuously sampled and analyzed in the field. This dye does not occur in the natural environment. It can be detected at dilutions of between 10^3 and 10^4 of the input concentration, adsorbs only weakly to sediments, and is chemically stable in the ground water system.

The study design took into consideration the hydrologic characteristics of western Maui and predictions of the transport time, transport paths, mixing, and dilution of the LWRF effluent within the ground water and in the coastal waters. An area of approximately 3,000 m by 3,000 m immediately offshore from the LWRF was investigated. The intent was to locate and map locations of seeps or plumes of dye and effluent entering the coastal waters and to investigate the rates of dilution in the water column. Discrete near-bottom water samples were collected to determine the nutrient characteristics of the effluent after reaching the coastal waters. Water column profile data were also collected.

Field Activities

Field operations commenced on July 1, 1993 with the first addition of fluorescent tracer to the effluent at the LWRF Injection Well No. 2. Slugs of approximately 9.5 L of 20 percent Rhodamine WT were added to the effluent every eight hours for three days. Continuous addition of tracer to Well No. 2 started on July 2, at a rate of 5 mL/min (7.5 L/day), and continued with occasional interruptions until August 28, 1993. Preliminary monitoring, to detect the initial tracer slugs in the near shore waters was conducted on eight days during the period July 3 - 12, 1993.

The main survey effort began on August 21, after 52 days of tracer injection at Well No. 2, and was completed on August 31, 1993. Over sixty hours of continuous fluorometry data were recorded along 36 transects spaced 100 m apart. Near-bottom fluorometry and temperature readings were taken at approximately 450 locations within the study area. Water samples were collected from 30 locations in the study area and at six reference locations outside the area. These samples were analyzed for salinity and eight nutrients. Twenty-two CTD casts were completed, resulting in water column profiles of temperature, salinity and density versus depth.

The final phase of the field effort started on October 10, 1993 and was completed on December 8, 1993. A total of 80 discrete near-bottom water samples were collected from ten locations within the study area approximately once every week for this period. The samples were analyzed in the laboratory for fluorescence in an attempt to detect the tracer should the residence time within the ground water system be greater than 60 days.

Lahaina Wastewater Reclamation Facility Operations

Normal operations were reported at the LWRF during the period of dye injection and field monitoring. Daily flows were recorded from the flow meter installed at the splitter box immediately up-flow from Well No. 2. Total daily effluent volumes passing through the facility were recorded from a flow meter located at the chlorination contact chamber. Effluent volumes injected into Well No. 2 averaged 3.0 million gallons per day (mgd). The total effluent injected into all the wells at the Facility averaged 5.6 mgd during the study period.

Summary of Findings

The major results of the study are summarized below:

The detection limit of the fluorometer was 0.02 ppb under the existing field conditions. For the tracer, Rhodamine WT, to be present but undetectable in the sampled water, dilutions of the tracer and the effluent of at least 3,200 to 5,900 times would be required.

Nutrient analyses showed mostly uniform concentration distributions with some elevated values. However, there was no correlation between nutrients at the locations of the peak fluorescence values, and no correlation between the occasional elevated nutrient concentrations and the spacial distribution of fluorescence could be identified.

Water column profile data showed nearly constant salinity with depth and approximately one degree Celsius temperature variation between the surface and bottom. These data indicated that the water was well mixed and no thermocline or trapping layer was present.

Background fluorescence concentrations varied between 0.04 and 0.06 ppb within the study area and at the reference stations. Concentrations between 0.01 and 0.3 ppb were recorded frequently in near-bottom water during the first half of the survey, but after investigation these readings were attributed to a light backscattering effect, a result of sand and smaller particles passing through the fluorometer. This source of interference was eliminated in the second half of the survey by installing two extra filters in the water intake line. Once the filters were installed, only a few samples with concentrations above 0.10 ppb were recorded.

Concentrations of near-bottom fluorescence generally fell within the range of the background variations, resulting in a data set with a small signal-to-noise ratio. Statistical analyses and contouring of the data identified five possible areas of elevated concentrations. However, at three of the areas the magnitude of the concentrations was close to the sensitivity limit of the fluorometer, and the fourth signal, although stronger, was a single reading of short duration. At the fifth area, in the southeast corner of the study area and approximately 300 m offshore, concentrations of three times background were recorded at two single but adjacent locations on two different days. The location is at the southern boundary of the study area in about 30 m of water. Freshwater seeps and bubbles had been previously reported in this area, but much closer to the shore in very shallow water (less than 2 m). Further investigation would be required in this area to confirm the presence of elevated tracer and effluent concentrations.

The following conclusions can be drawn from the results of the study:

- Elevated concentrations of tracer were recorded at five near-bottom areas within the study area. However, these readings of between 0.02 to 0.12 ppb above the background concentration were either at the limit of sensitivity of the instrumentation or were recorded for very short durations. Consequently, it can not be stated conclusively that the tracer was present at the time of sampling. Further intensive sampling would be required at each of the five locations to verify the presence of elevated effluent concentrations.

- At all other areas within the study area, the tracer was not detected. For the tracer to be present and undetectable, the tracer and the effluent with which it was mixed, must have undergone dilutions of between 3,200 and 5,900 times the injection concentrations. If the tracer was present at detectable levels, it was diluted below detection concentrations before reaching any sampling points, or it was present during times that sampling was not being conducted at that area. If it was present in the near-bottom water, the tracer had been diluted to undetectable concentrations vertically within the first 10 to 30 cm of the bottom, or horizontally within 100 to 200 m of its seabed source.

- The probability of tracer entering the coastal waters within the study area as a single plume is very low. It is more likely that if the tracer was present, it influxes through a large number of discrete points or through one or more wide-area seeps at low flow rates.

- No correlation is evident between the fluorometric survey results and the nutrient analyses or the long-term post-survey fluorescence analyses.

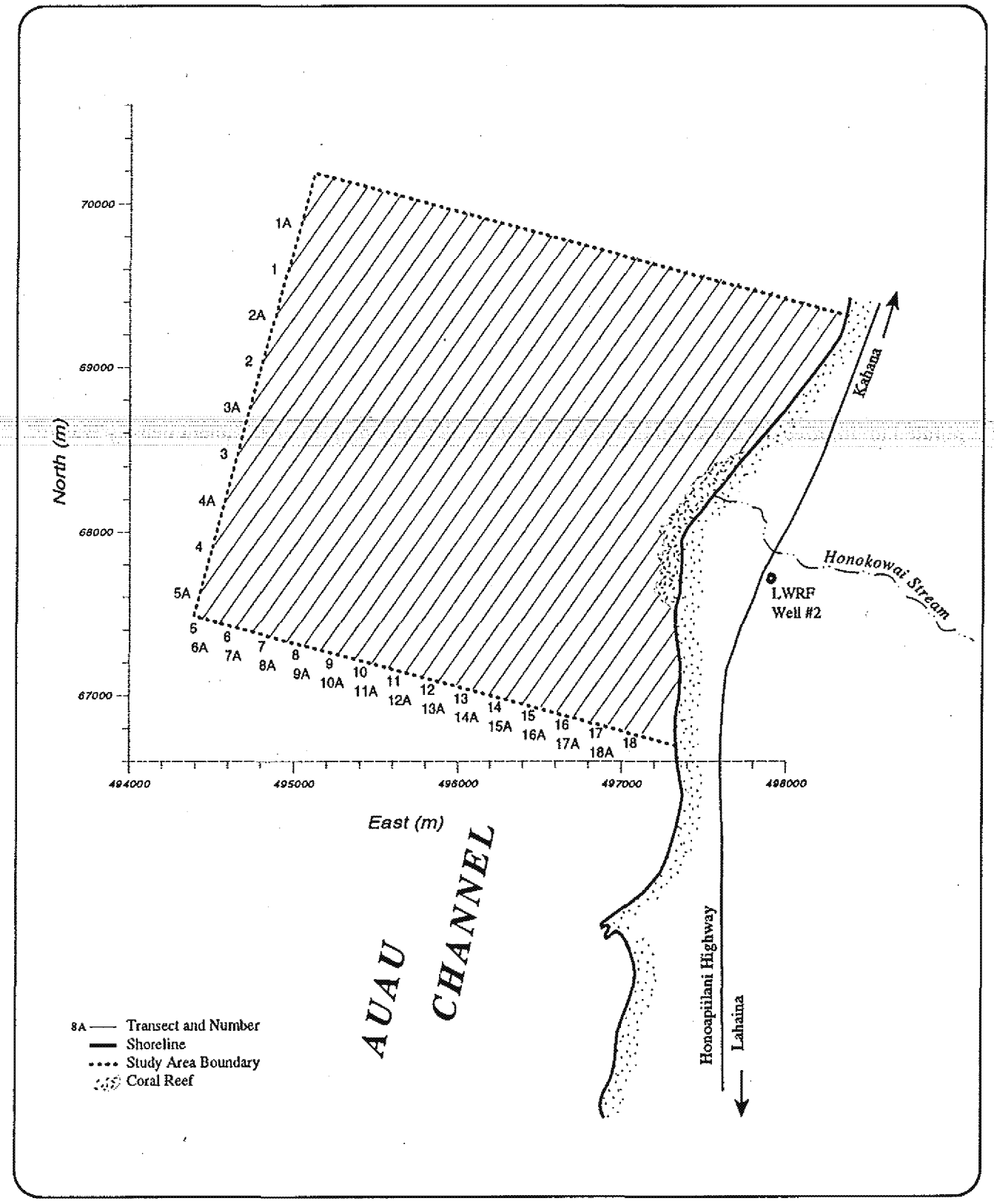


Figure 3-4. Location of survey transects within the study area.

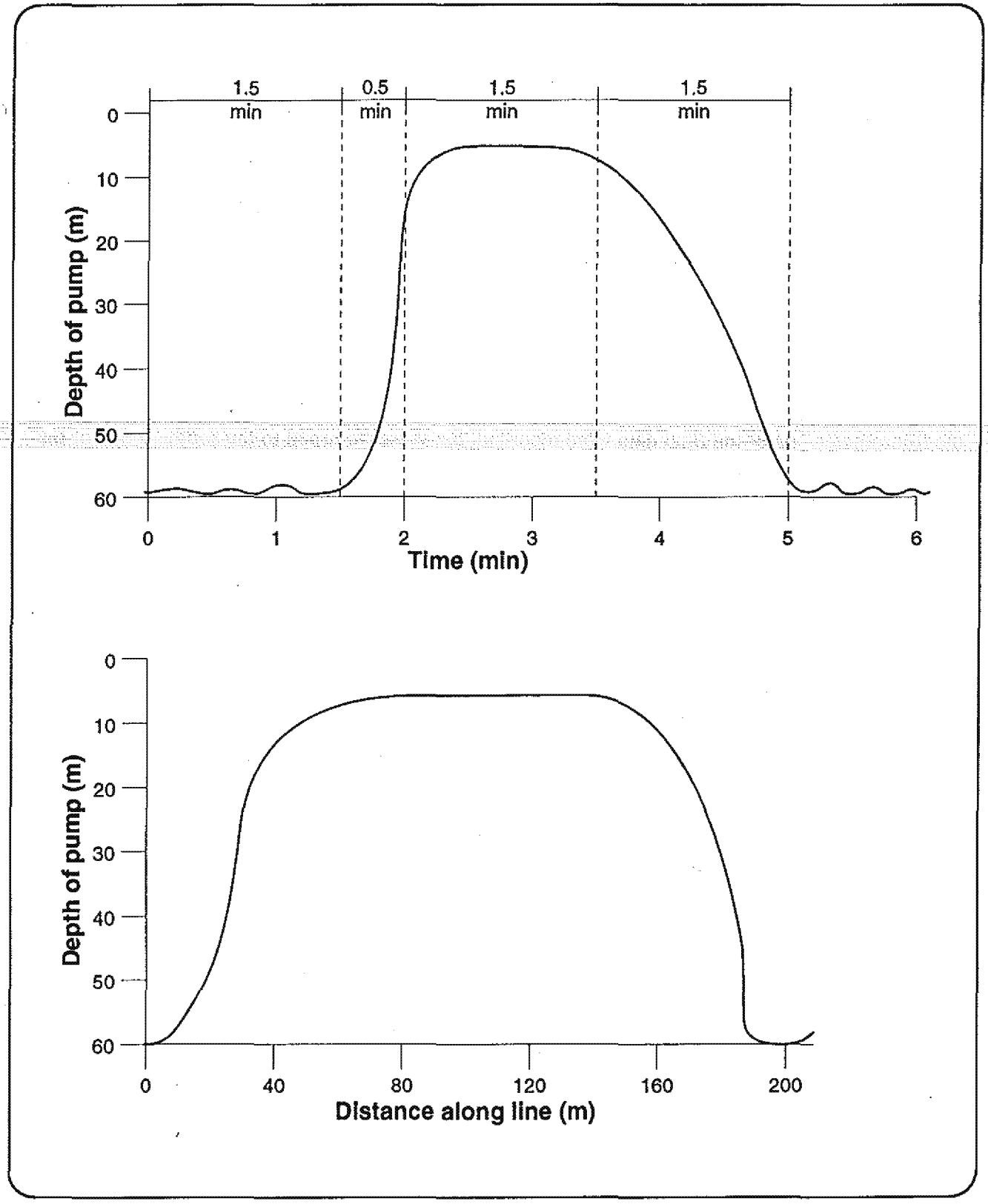


Figure 4-1. Typical pump depth versus time and distance between adjacent sampling stations.

- contour charts for near-bottom fluorescence were compiled and plotted from the 3-sec averaged data collected from each half of the survey to be used as tools in the analysis of spacial patterns of the signals and to present the final interpretation of the data.

5.3.1 Fluorescence and Temperature Graphs

Graphs of fluorometry data, as concentrations reported relative to a calibration standard of 1.00 ppb of Rhodamine WT, and of temperature (°C), are presented in Appendix A in order of transect number. The data are raw 3-sec averaged values, as recorded by the internal data logger of the fluorometer. Corrections for the approximate 2 min travel time between the pump and the instrument have not been applied, nor are the data corrected for background fluorescence. Instantaneous fluorometer readings were recorded separately every 15 sec onto the navigation computer hard drive. After an initial analysis using the 15-sec instantaneous data, the 3-sec averaged data were chosen for a more detailed analysis because the data were recorded more frequently and the data were more consistent than the instantaneous data. The data were considered a more accurate representation of conditions during the study because, for a typical sampling location, the near-bottom water was pumped through the fluorometer for approximately 1.5 min and during this period only six 15-sec values were recorded compared to thirty 3-sec values.

Three major characteristics of the data could be discerned from the line graphs:

- oscillations in temperature readings occurred consistently throughout both halves of the survey and related small variations of concentration were evident on some lines

- many distinct peaks of fluorescence at two to three times background values were recorded when the pump was near the bottom during the first half of the survey

- variations in fluorescence were much smaller and were close to the detection limit of the instrument during the second half of the survey when two extra filters were installed in the water intake line.

Temperatures were seen to vary consistently by about 1 °C along each transect. The lower readings correspond to near-bottom water temperatures and the higher readings to the surface water temperatures. Corresponding small-scale oscillations, in the opposite direction, were discernible in the fluorometer readings for most transects. These oscillations were generally at or below the sensitivity limit of the instrument. They were through to be the result of backscattering by very fine particles

near the seafloor, or inaccuracies in the temperature compensation circuitry, or a combination of both. These effects were more pronounced because the background signal was very low and the fluorometer is operating at the low end of its sensitivity range (S. Mokelke, January 17, 1994, personal communication).

The majority of high values were recorded during the first four days of the survey. These elevated signals were associated with near-bottom water samples, and during the initial days of the survey, they were thought to be real signals. However, sand particles were detected in the water at the fluorometer outlet. It was then realized that, as the weight and pump moved across the seafloor, sand and finer particles may have been disturbed and sucked into the intake hose. As the particles passed through the flow-cell of the fluorometer, light was refracted from the particles at different frequencies, creating false readings. To verify this possible source of interference, background near-bottom samples were measured at a shallow site remote from the study area. Similar elevated readings were recorded as the pump and weight were observed moving across the seafloor. To compensate for this interference for the second half of the survey two extra filters were installed in the hose line to trap suspended particulates before the water entered the fluorometer measuring cell.

As further verification of interference, several discrete water samples were collected along different transects at the same time the fluorometer was recording high readings. These discrete samples, all of which contained visible particles, were analyzed later the same day using the fluorometer set up in a discrete sample measuring mode. No elevated readings were recorded if the samples were not stirred before being poured into the measuring cuvette (Table 5-1). The same sample, if stirred briskly before pouring into the fluorometer cuvette, was measured at a higher concentration than the unstirred sample, indicating that the higher reading was a result of backscattering of the light signal by the particles in suspension. Because of the presence of the particles and the variations in readings, the elevated flow-through readings recorded in the first 4 days of the study were considered to be the result of light backscattering. If true signals were present, they would have been masked by this interference.

Post-survey analysis of all the data sets supported the presence of interference in the samples collected during the first half of the survey. In general, elevated readings were present only along every second transect, and did not occur along adjacent transect lines. An example of this can be seen from the following figures. Figure 5-4 is a line graph of fluorescence of the unfiltered water versus time recorded on transect Line 4. Elevated signals, due to suspended particulates in the sample, are obvious at nine near-bottom stations. Figure 5-5 shows the equivalent graphs for the adjacent Line 4A and Line 5A (100 m to the east and west of Line 4, respectively), in which the water passed

TABLE 5-1. DISCRETE SAMPLING CONCENTRATIONS

Transect No.	Date	Sampling Time	Concentration (ppb) Flow-through	Discrete sample
4	8/24/93	11:20:00	0.232	0.027
4	8/24/93	11:54:20	0.27	0.033
5	8/24/93	7:38:55	0.115	0.042
6	8/24/93	9:11:11	0.117	0.036
6	8/24/93	9:37:40	0.15	0.024
6	8/24/93	9:41:50	0.165	0.023
6	8/24/93	10:22:50	0.137	0.026
2	8/25/93	10:50:33	0.12	0.021
3	8/25/93	9:09:08	0.14	0.018
3	8/25/93	9:28:20	0.135	0.019
3	8/25/93	9:31:25	0.122	0.018
7	8/25/93	7:14:10	0.117	0.019
1A	8/27/93	11:46:10	0.056	0.018
5A	8/27/93	8:17:10	0.057	0.017
6A	8/27/93	11:11:25	0.058	0.016
7A	8/28/93	8:43:20	0.065	0.016
8A	8/28/93	9:25:00	0.08	0.017
16A	8/29/93	13:33:00	0.065	0.024
15R	8/30/93	11:54:10	0.05	0.019

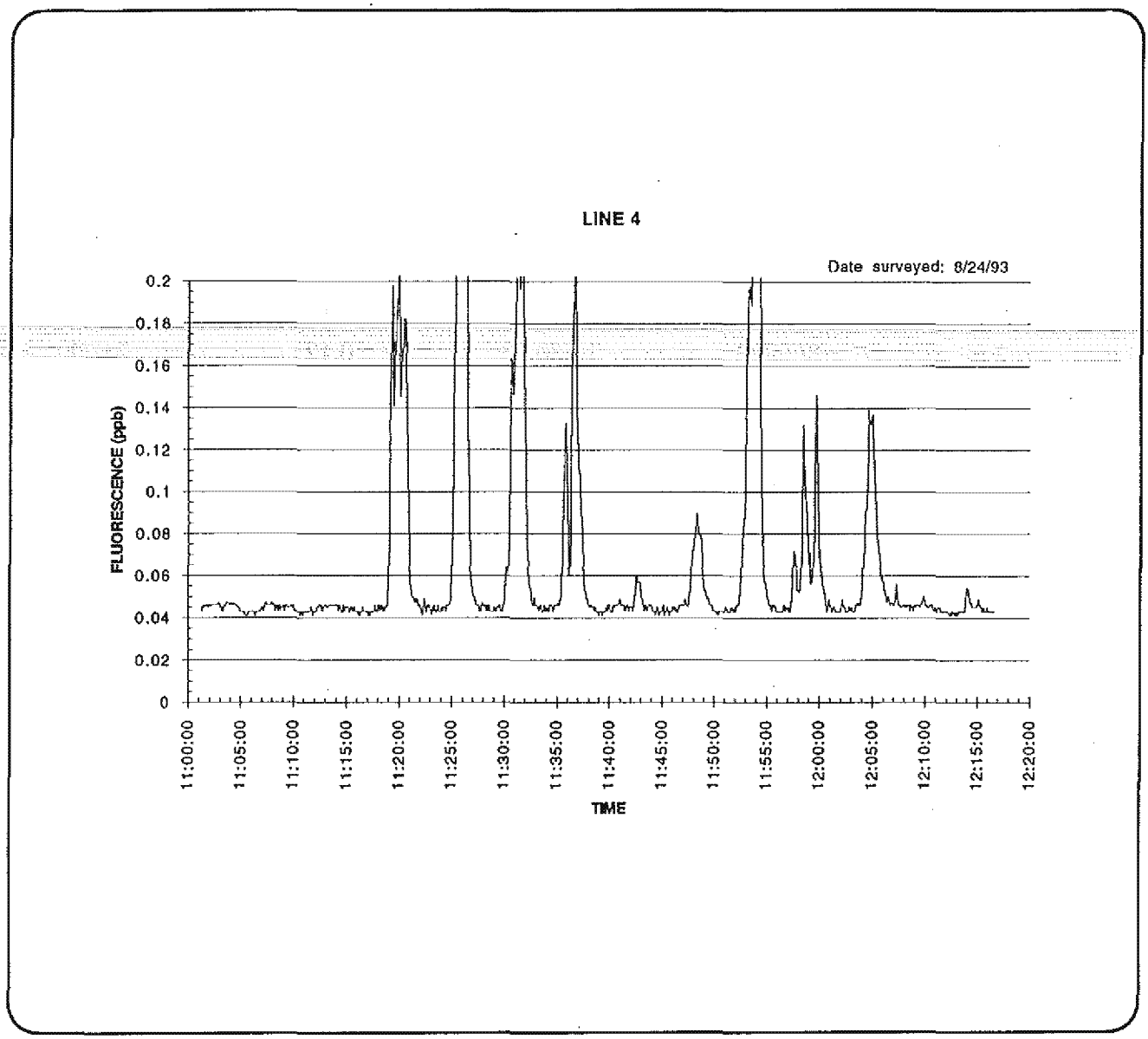


Figure 5-4. Fluorescence readings recorded on Line 4 with one filter in-line.

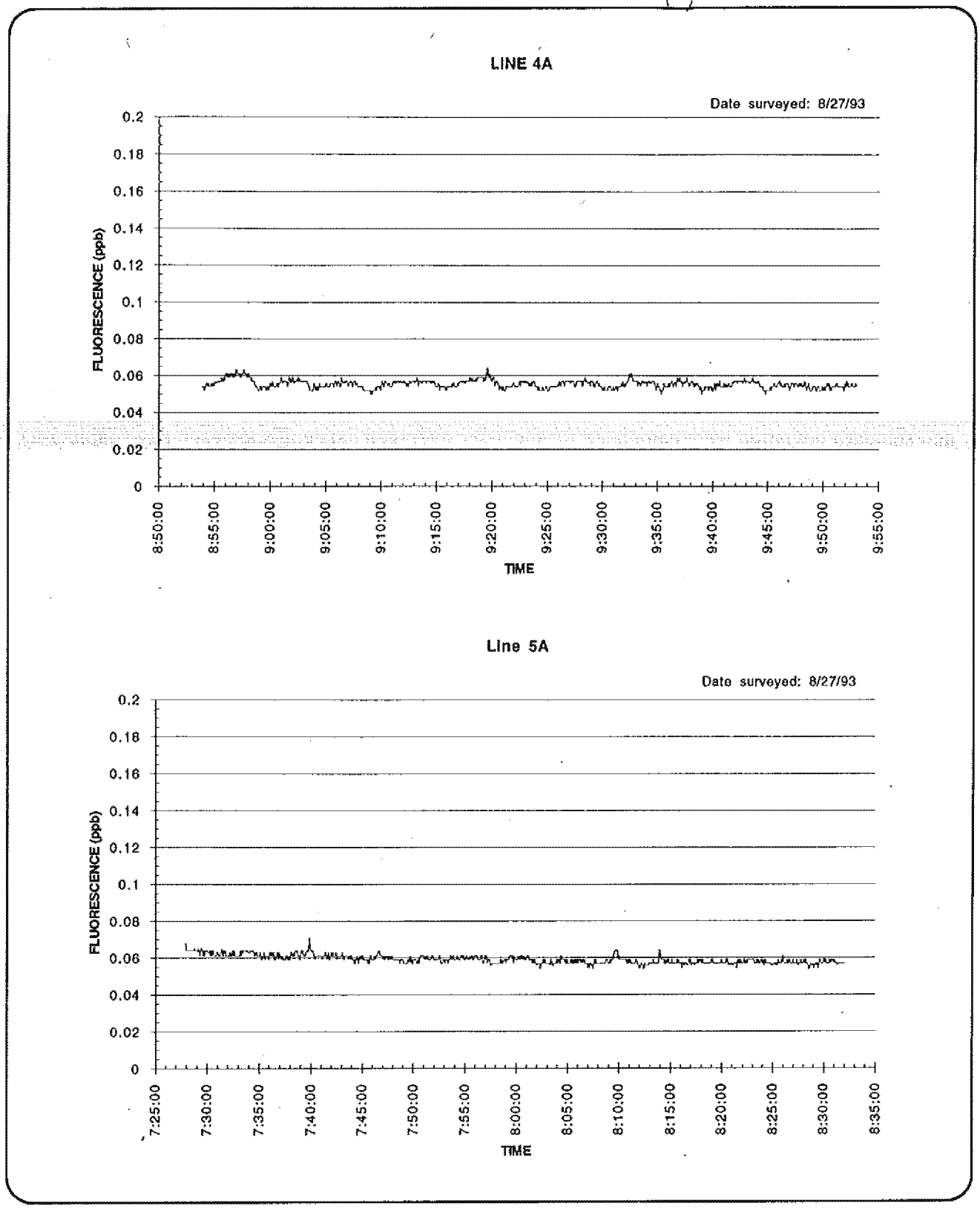


Figure 5-5. Fluorescence readings on lines adjacent to Line 4, using three in-line filters.

through two additional filters before reaching the fluorometer. These plots show only a small variation of concentration of 0.05 - 0.07 ppb. This alternating pattern of high readings and near background readings along adjacent transects was repeated along other transects, which supports the concept that the elevated readings were a result of an interference mechanism, and are not representative of a naturally occurring effluent discharge pattern.

5.3.2 Statistical Analysis

Overall, not considering signals resulting from interference from suspended particulates, the data are characterized by a small signal-to-noise ratio and the variations in readings for the majority of the data are small and close to the limits of deductibility of the instrument. A simple statistical analysis of the data was performed to identify possible signals within the background variations. The mean and standard deviation were calculated for the 3-sec averaged data collected each day (Table 5-2). These data were plotted as scattergrams of daily observations versus concentration, and the mean value and 95-percent confidence limits, represented by 1.65 standard deviations were plotted also (Appendix B). Points falling outside the upper confidence limit were identified for further inspection, after the data were contoured, to determine the extent of continuity of elevated values across adjacent transects.

5.3.3 Fluorometric Contours

The third part of the data analysis was to identify possible spatial patterns of variations of concentrations in the near-bottom waters. Contour charts of near-bottom fluorescence were prepared from the 3-sec averaged data and the navigation records of the vessel's position when the pump and first reached the bottom. Fluorescence and position readings were corrected for the time delay of the water travelling through the intake hose. After these corrections were applied, the concentration values corresponded to the horizontal grid position at which they were recorded.

Where sections of transects had been resurveyed to verify areas of elevated concentrations, the highest readings were plotted initially and the subsequent resurvey data, which were lower in all cases, were not used in the contour plots. This was done to ensure that no valid elevated readings were discarded.

Because of the interference encountered in the first half of the survey and because each half of the survey covered the entire study area, the data collected from each half were contoured separately. This approach was used as a further step to confirm whether the peak concentrations recorded during the first half were valid signals or the result of interference. If the signals were indeed valid, then the

TABLE 5-2. DAILY STATISTICS OF FLUOROMETRIC DATA

Date	Mean	Std. Dev	Minimum	Maximum	Range	Count
Single in-line filter. Transects 1 through 17						
8/22/93	0.053	0.014	0.043	0.28	0.237	5517
8/23/93	0.051	0.0074	0.043	0.117	0.074	4776
8/24/93	0.06	0.032	0.041	0.405	0.364	3107
8/25/93	0.052	0.011	0.039	0.115	0.076	5554
Three in-line filters. Transects 1A through 18A						
8/27/93	0.057	0.0045	0.048	0.078	0.03	6132
8/28/93	0.051	0.0089	0.041	0.082	0.041	6866
8/29/93	0.05	0.0034	0.045	0.086	0.041	6358
8/30/93	0.052	0.0063	0.045	0.187	0.142	4052

two plots of contours of equal concentration should exhibit similar spatial patterns. However, this was not the case.

Initially, near-bottom concentration values were plotted relative to the grid locations (easting, northing) at which the values were recorded. This was done for each half of the survey (Figures 5-6 and 5-7). Although these plots of spot values show the complete data sets, they are difficult to interpret. So, the data set from each half of the survey was then computer-contoured to produce plots of lines of equal concentration (Figures 5-8 and 5-9). For each chart, the corresponding positions of the data points used for the contouring were plotted as small dots. Each dot corresponds to the concentration value shown on the previous figures (Figures 5-6 and 5-7).

These 0.01-ppb contour plots show distinct concentration patterns. The apparent southwest-northeast trend in the concentration contours is thought to be an artifact of the data collection procedure because each transect was run in the same northeasterly direction.

The plot of the first half of the data (Figure 5-8) exhibits high concentrations in the western section of the study area, most corresponding to data collected along Line 4 and Line 6. A single high value is evident at the beginning of Line 2 along the western edge of the area, and another is evident in the southeast corner, at the beginning of Line 17. These characteristics and the overall structure of the pattern can be seen more clearly in Figure 5-10, in which only contours greater than the background value of 0.06 ppb are plotted.

Figure 5-9 shows the contours generated from the data collected in the second half of the survey, when the water passed through three filters before reaching the fluorometer. This plot is very different from Figure 5-8. No elevated concentrations were present in the northwest section of the study area and the concentrations overall were much lower. The only exception was a single high value in the southeast corner. Again, these characteristics can be seen more clearly in Figure 5-11, in which only contours greater than 0.06 ppb are plotted. The considerable difference between the plots from each half of the survey are more obvious when Figures 5-10 and 5-11 are compared.

5.3.4 Data Interpretation

The lack of continuity across transects for the high concentrations recorded in the first half of the survey suggest that the observed contour patterns did not result from the presence of tracer, but are caused by interference to the fluorescence signal. In only one instance are high concentrations observed across adjacent lines. This occurs at the southeastern corner of the study area, where maximum values of 0.18 ppb were recorded at the beginning of Line 17A and at the beginning of

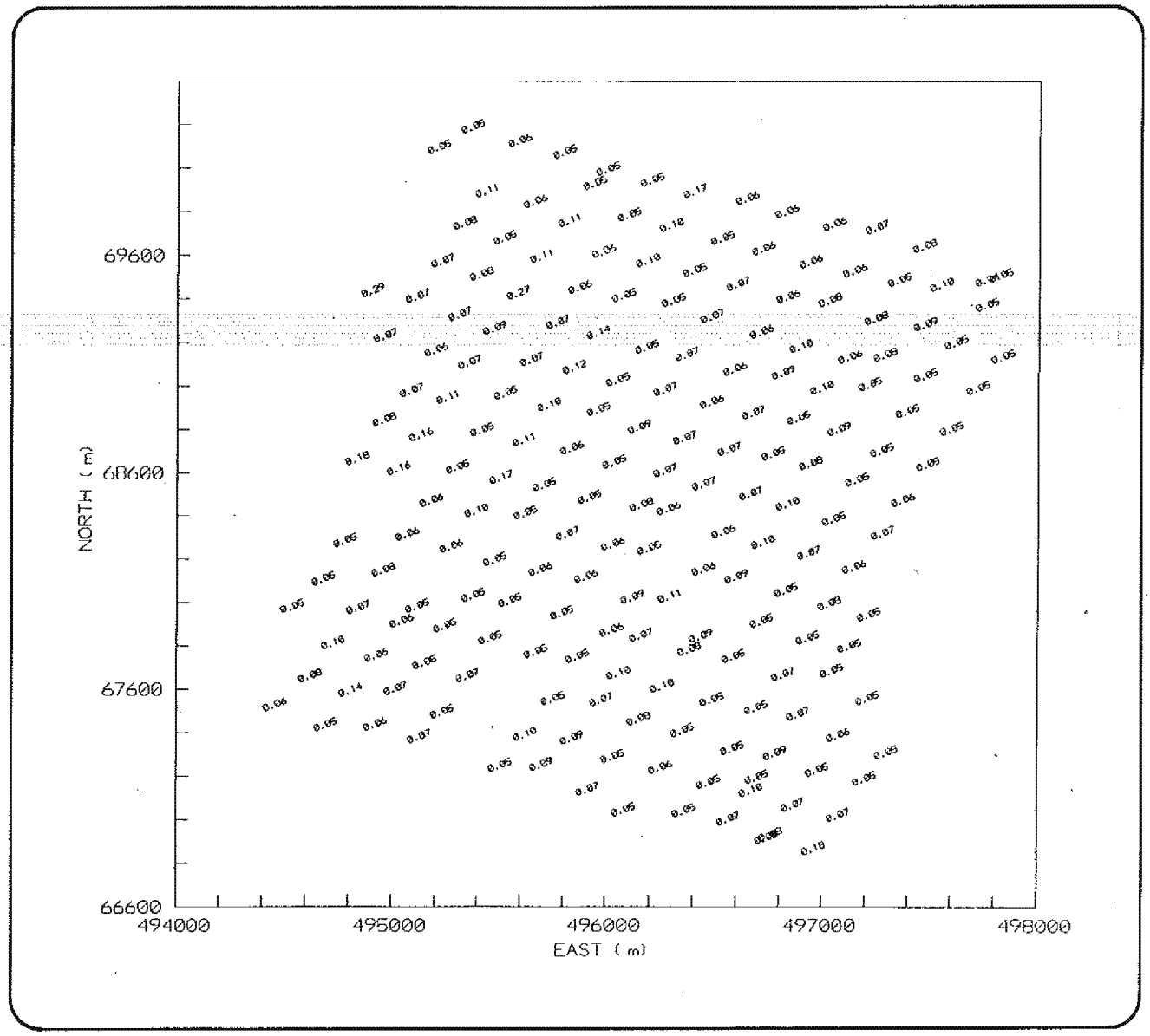


Figure 5-6. Concentration (ppb) versus grid location for unfiltered samples.

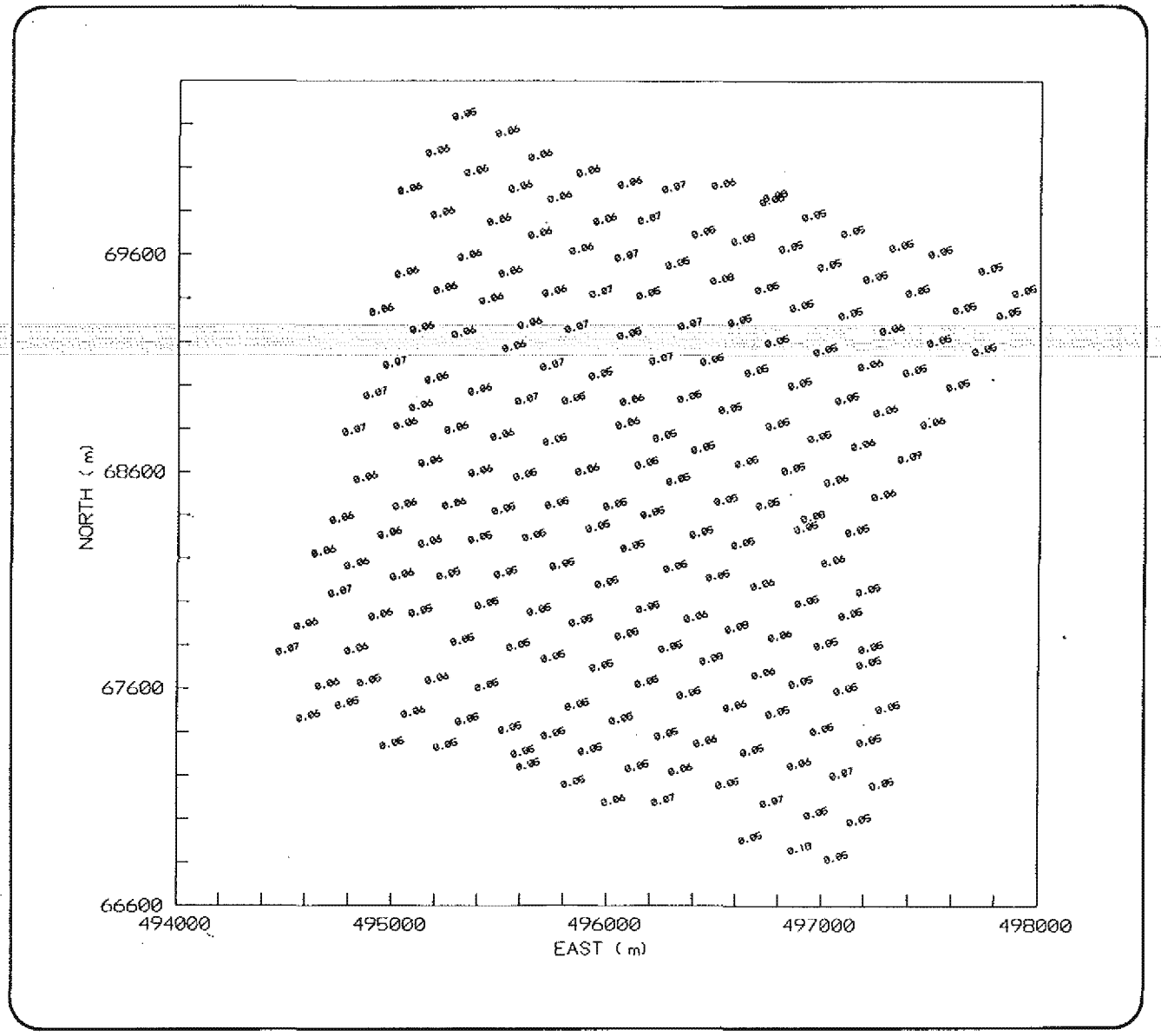


Figure 5-7. Concentration (ppb) versus grid location for filtered samples.

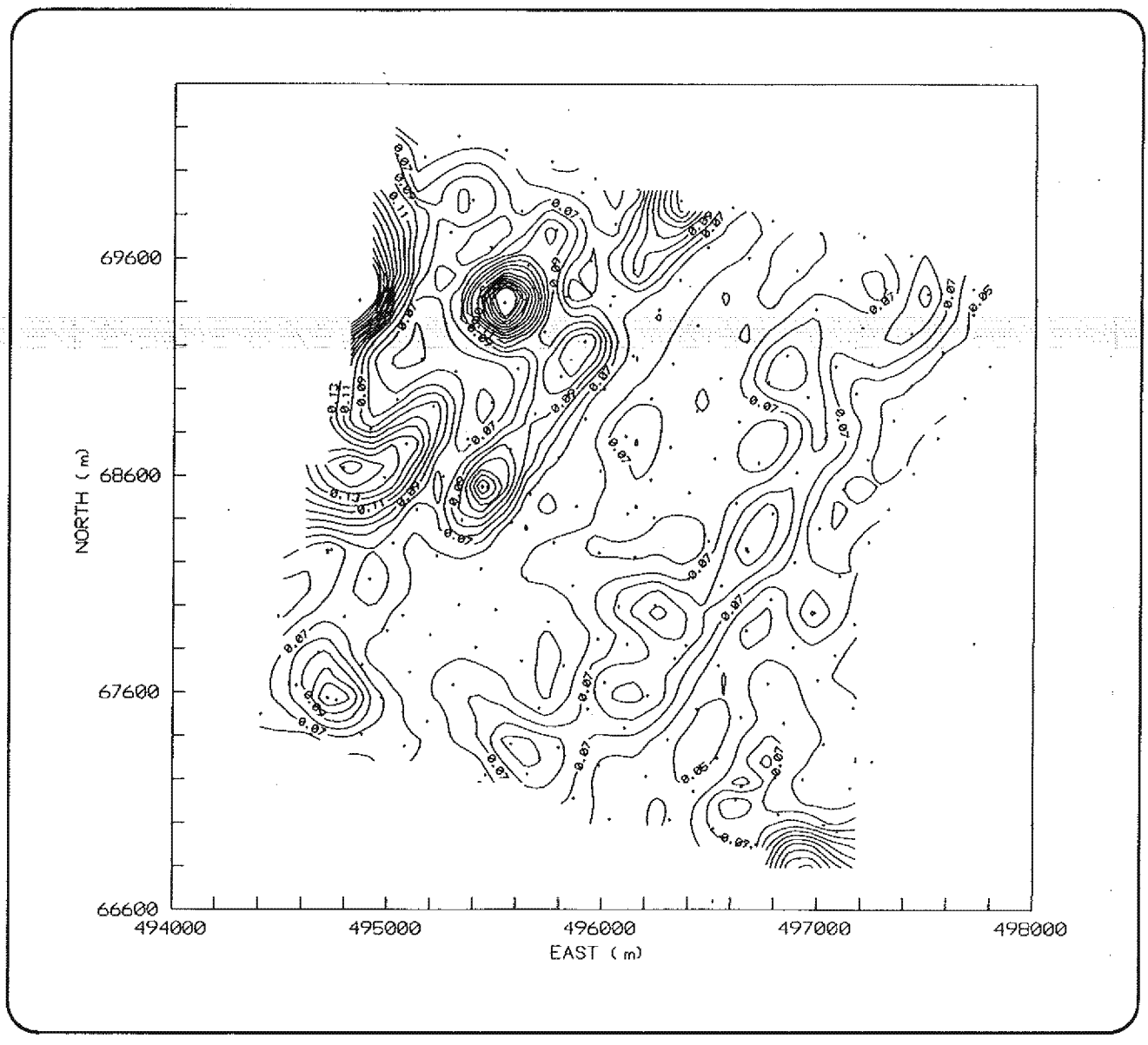


Figure 5-8. Concentration contours (ppb) for unfiltered samples.

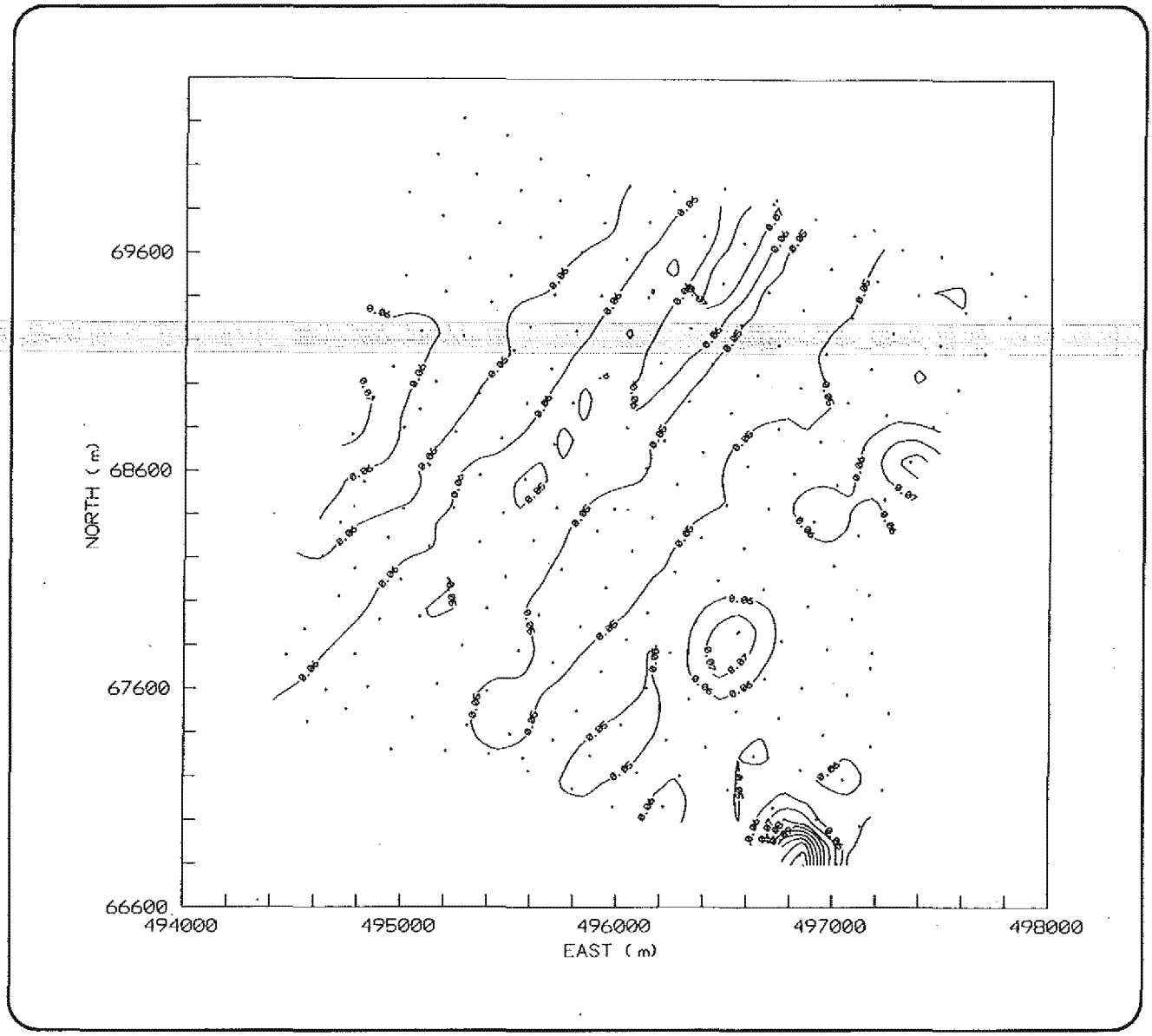


Figure 5-9. Concentration contours (ppb) for filtered samples.

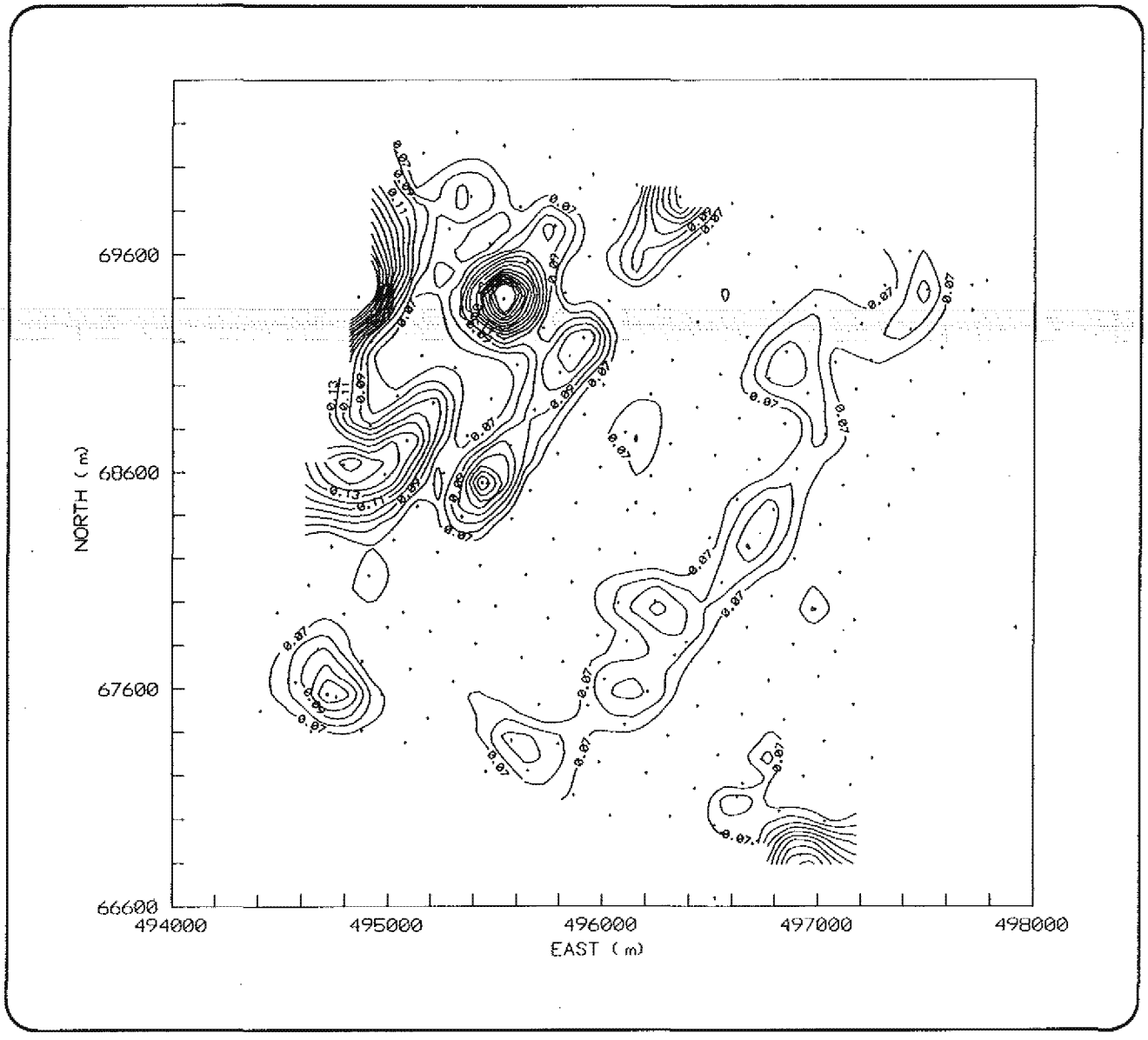


Figure 5-10. Concentration contours greater than 0.06 ppb for unfiltered samples.

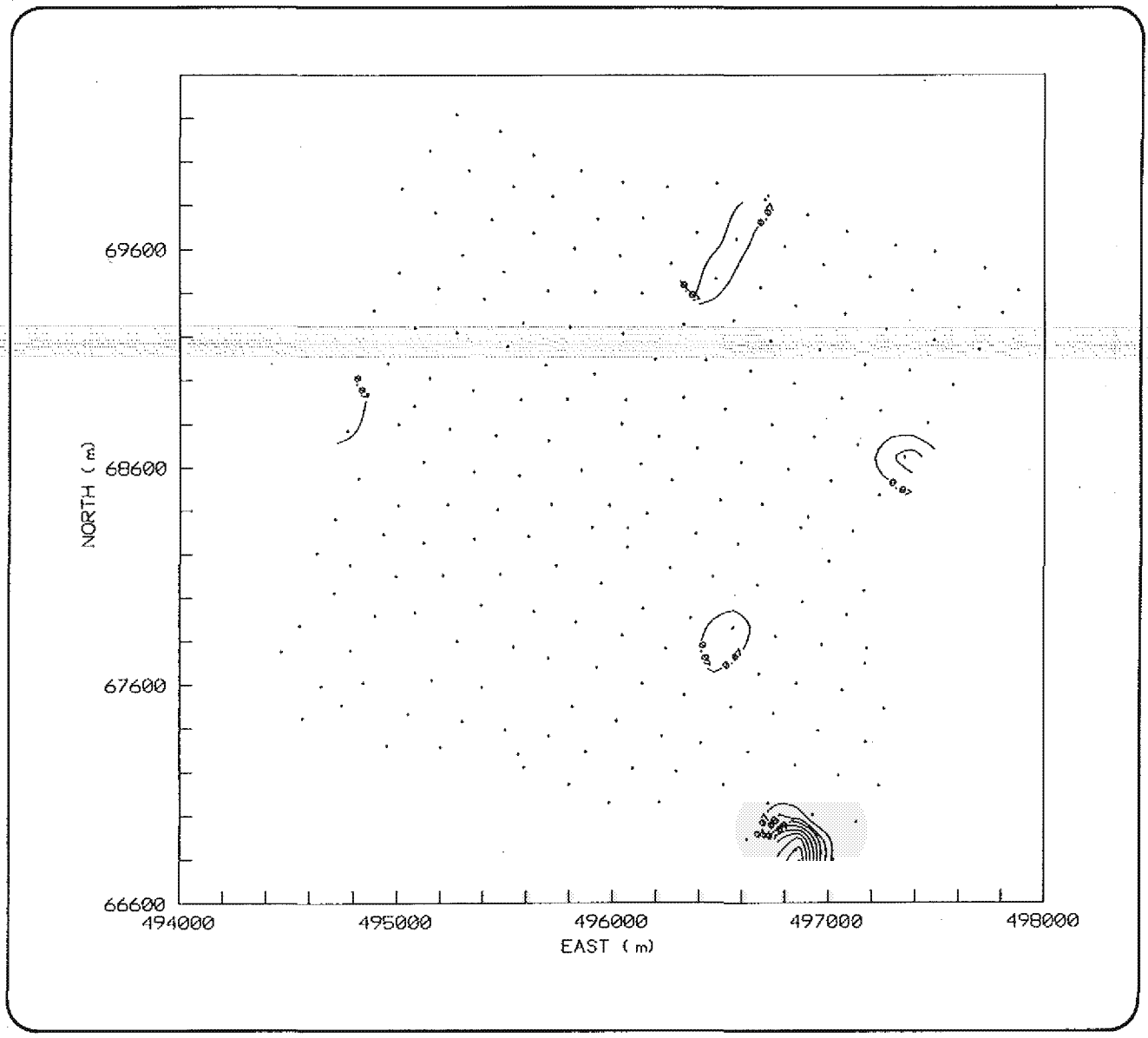


Figure 5-11. Concentration contours greater than 0.06 ppb for filtered samples.

Line 17. Inspection of the concentration point plots (Figures 5-6 and 5-7) show near background concentrations adjacent to both high values. In both instances, elevated readings were recorded from near-bottom water and for durations of about 1.5 min, which is the approximate time the pump was near or on the bottom. However, elevated signals were not recorded at other adjacent locations, 200 m to the north or east, or 100 m to the west. Both of the readings occurred at the beginning of transects, and no data was collected south of either location.

From Figure 5-11, four other areas of concentrations above background are evident. On the western edge of the study area are two points at the beginning of Line 3A with values of 0.75 and 0.72 ppb. The differences between these values and the background are close to the limit of sensitivity of the instrument. Adjacent data from the first half of the survey is probably masked by interference and cannot be used to support the existence of elevated concentrations in this area.

At the northern edge of the study area, five points between 0.075 and 0.082 ppb were recorded along Line 8A (see Appendix A). These signals exhibited different characteristics than other peaks measured during the survey. Usually, the minimum values remained constant at background levels and a large variation in concentration occurred only in the near-bottom water. In this case, the minimum concentration also increased approximately 0.02 ppb above background and the variation between maximum and minimum values did not vary markedly from other background transect data. This suggests that if increased fluorescence was detected, it was detected throughout the water column, and not just in the near-bottom waters.

This section of Line 8A was resurveyed twice, on 8/29/93 and on 8/30/93, in an attempt to verify the initial readings. Both times no concentrations above background levels were recorded. The data from the resurveys are not incorporated in the data for Figure 5-11. The lack of repeatability of elevated readings suggest that the original readings were a result of an unknown interference mechanism and elevated concentration did not exist; or if a true signal was present, it represented a narrow plume of slightly elevated concentration which varied with location or time. That is, during the periods of the resurveys, the concentration had diminished or the location of the plume had shifted to the east or west. However, because the current was observed to flow consistently in a northerly direction, it was unlikely a plume would move that far. Temporal variations in the rate of flow of a plume cannot be explained, either. Injection rates at the wells were relatively constant, and flow paths through the ground water system are also thought to be consistent.

The third area of elevated readings occurred along the eastern boundary of the study area, along transect 14A. Inspection of the line graph in Appendix A shows a single sharp peak (to 0.94 ppb) of

duration of approximately 30 sec. Adjacent records from Line 13 and Line 14 indicate background levels only. If this is a valid reading, the elevated concentrations remain close to the seafloor and concentrations fall to background levels rapidly, estimated to be within 10 m of the detection point.

The fourth area of elevated readings is marked by the small 0.07 ppb contour to the south of the center of the study area. This occurred on Line 13A where three readings greater than 0.07 ppb were recorded (Appendix A). Data from the adjacent transect to the west, Line 12, appears to be masked by backscattering interference and data from the adjacent Line 13, to the east, shows a single elevated peak but it is further north along the line. If these readings on Line 13A represent true elevated concentrations, the concentration falls to background levels within 100 m to the east and west and varies for 1,000 m north along the line from 0.08 ppb to background levels.

The data and the field logs were inspected carefully for each of the locations and times discussed and no obvious problems that would result in interference or false readings were identified. However, interference, or false readings from unknown sources or from instrumental variations cannot be completely ruled out when the signals are of similar magnitude to the background variation and the instrument detection limit, and four of the five possible valid signals are close to the limit of sensitivity of the instrument. The fifth signal, at the southeast corner of the study area, was detected on adjacent lines on two separate days, but in each case, at only one location. Of all the elevated concentrations recorded, this location was the most likely to be a valid detection of tracer. However, without further data, especially to the south of the location, it cannot be positively stated that tracer was present at the time and location of sampling.

5.3.5 Dilution Calculations

The tracer was added to the effluent injected into Well No. 2 at a daily average volume of 1.5 L of active dye. The average effective tracer concentration at the wellhead was between a minimum of 71 ppb, compared to the average total daily flow of the LWRF of 5.6 mgd (21.2×10^6 L/day), and a maximum of 132 ppb, using only the average effluent flow at Well No. 2 of 3.0 mgd (11.4×10^6 L/day). The possible loss of active tracer due to uncontrolled mechanisms, such as oxidation and adsorption were estimated to be not more than 10 percent.

The field resolution of the fluorometer was estimated to be approximately 0.02 ppb. The background concentrations within and beyond the study area varied from 0.04 to 0.06 ppb. Based on these values, for the tracer to be present in the study area at undetectable limits, dilutions of at least 3,200 ([71 ppb x 0.9]/0.02 ppb) would be required, assuming the effluent from all four wells is

completely mixed in the ground water. Dilutions of 5,900 ([132 ppb x 0.9]/0.02 ppb) would be necessary if the effluent from Well No. 2 did not mix with the effluent from the other wells after injection.

Along Line 13A where concentrations of 0.08 ppb were recorded (0.02 ppb above background), the estimated dilution of the effluent and tracer, if present, was close to the maximum detectable dilutions of 3,200 to 5,900. Along Line 14A, at the location of the brief high reading of 0.09 ppb, the minimum dilutions required to achieve the recorded value were 2,100 to 3,900. At the southeast corner of the study area, where two separate values of 0.18 ppb (0.13 ppb above background) were recorded, effluent dilutions would be between 500 and 900 times the wellhead concentrations, again depending on the mixing characteristics of the effluent after injection. However, these dilutions would have to exceed the maximum detectable values of 3,200 to 5,900 within 100 m to reach the observed background concentrations at the surrounding sampling points.

In summary, five possible areas of elevated fluorescence were identified from the triple-filtered samples collected during the second half of the survey. At three of these areas, elevated concentrations were 0.02 to 0.03 ppb above background values. This variation was similar to the background variation reported over the duration of the survey, and similar to the field detection limit of the instrument. The fourth signal consisted of a single short duration peak reading. The fifth area, where two concentrations of 0.18 ppb were recorded at the beginning of two adjacent lines on two separate days, was located in the extreme southeast corner of the study area. None of the results can, however, be conclusively shown to indicate the presence of elevated tracer concentrations.

5.4 Nutrient Analyses

The results of the nutrient analyses of the 36 samples collected are summarized in Table 5-3. The sample numbers correspond to those shown in Figure 4-3. Maps of the location and values of each nutrient sample are presented in Appendix C. Figures 4-2 and 4-3 show the respective location of the reference stations and of the water samples collection stations within the study area.

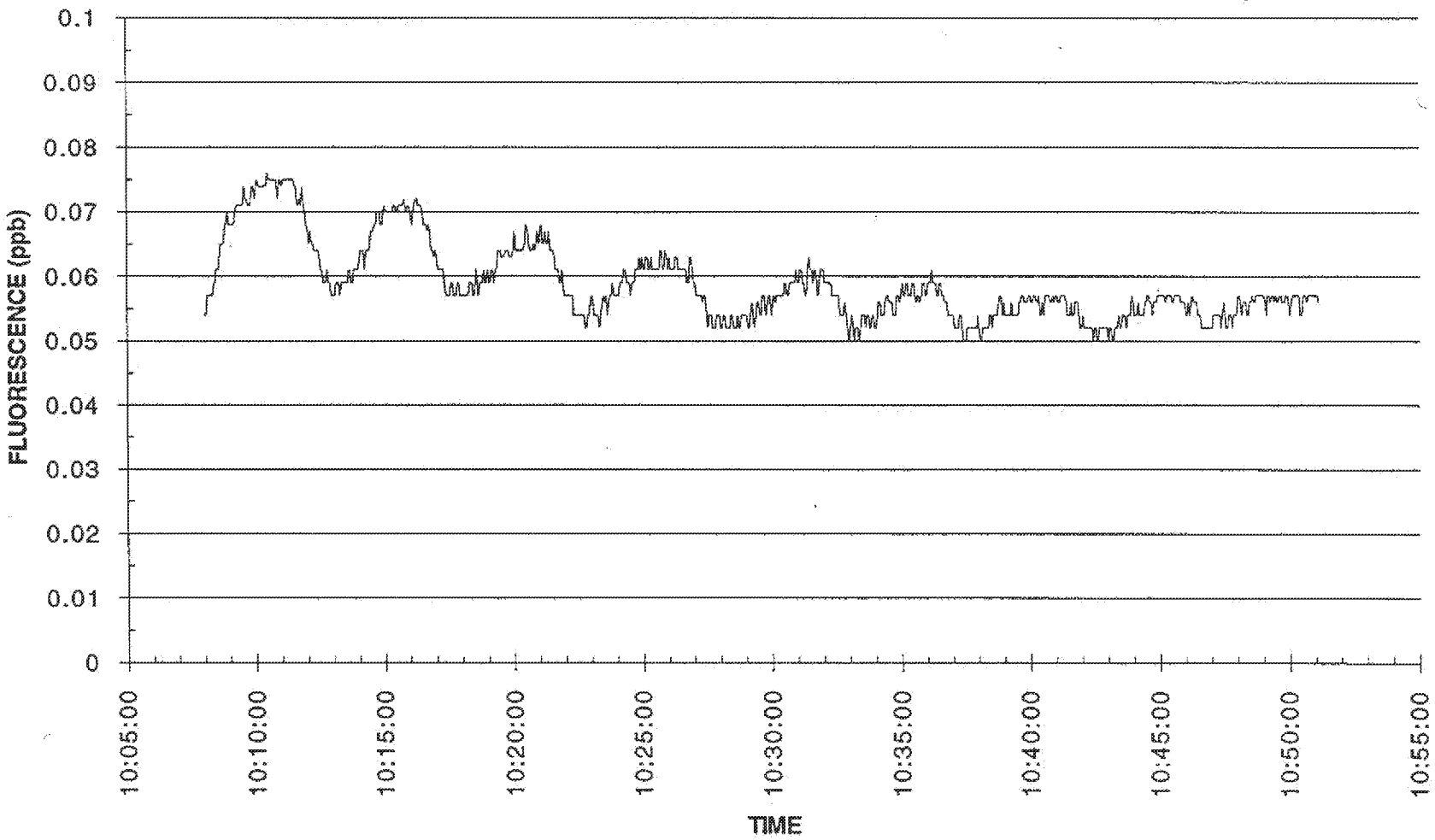
At the northeast corner of the study area, in shallow water close to the shore, a single nitrate-nitrite (NO3) concentration of 0.19 µM was recorded. Another high concentration of 0.11 µM was recorded near the mouth of Honokawai Stream. These values were significantly higher than the mean value of 0.042 µM. Nearly all other values were within 0.01 µM of the mean value.

Appendix A

Graphs of Fluorescence and Water Temperature
(3 - second averaged data)

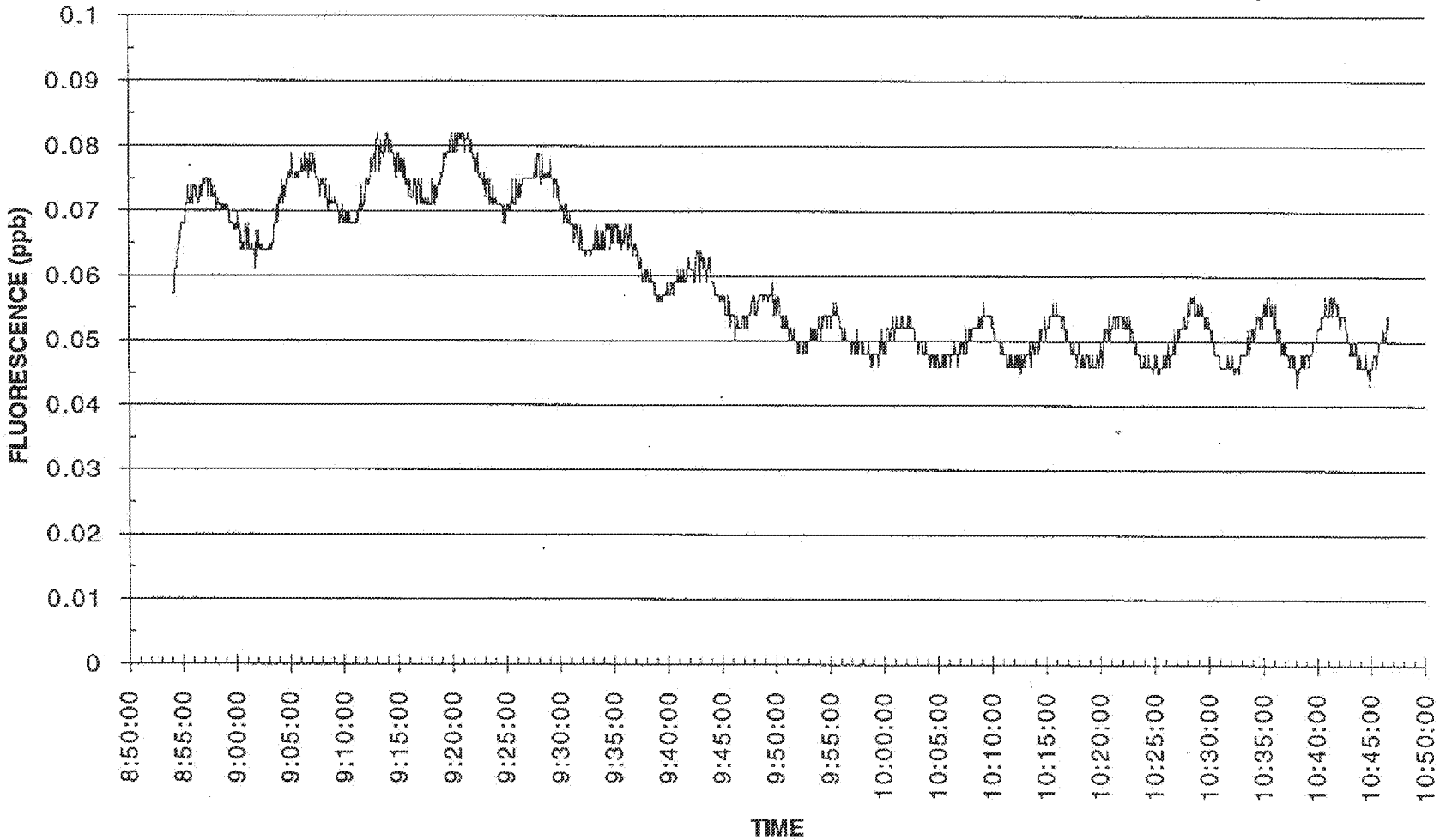
LINE 3A

Date surveyed: 8/27/93



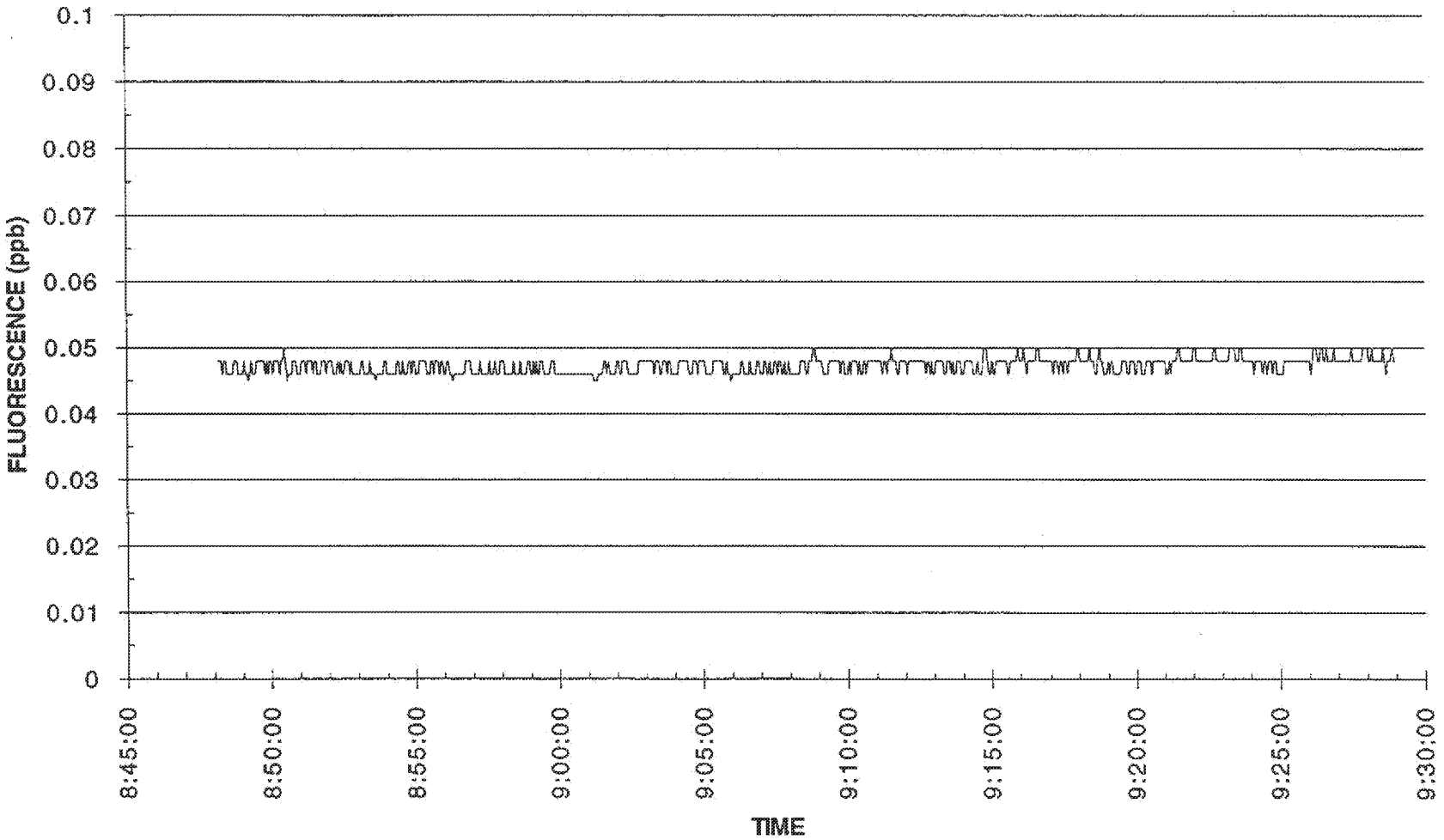
LINE 8A (REVERSE)

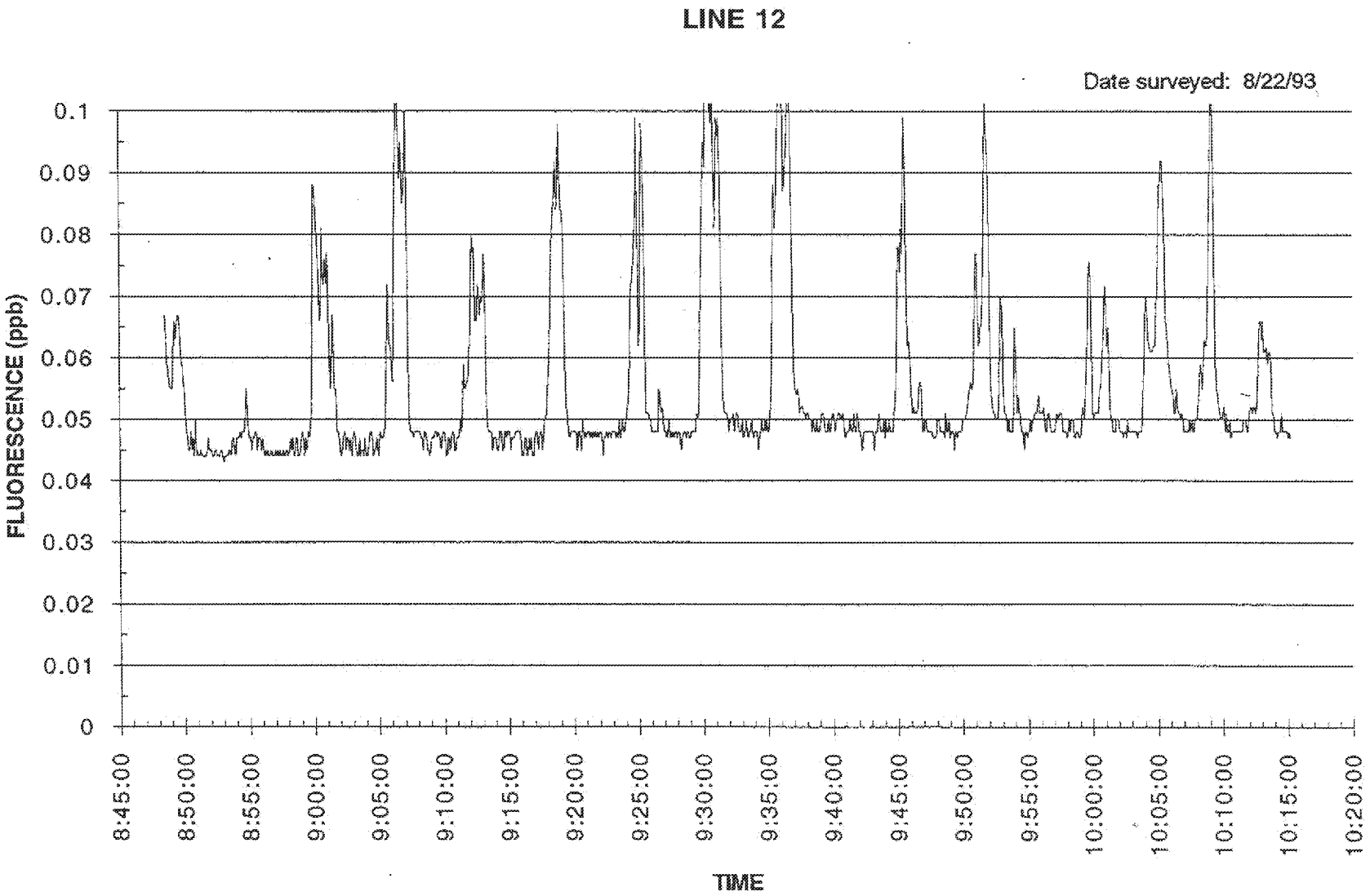
Date surveyed: 8/28/93



LINE 8A (REPEAT/REVERSE)

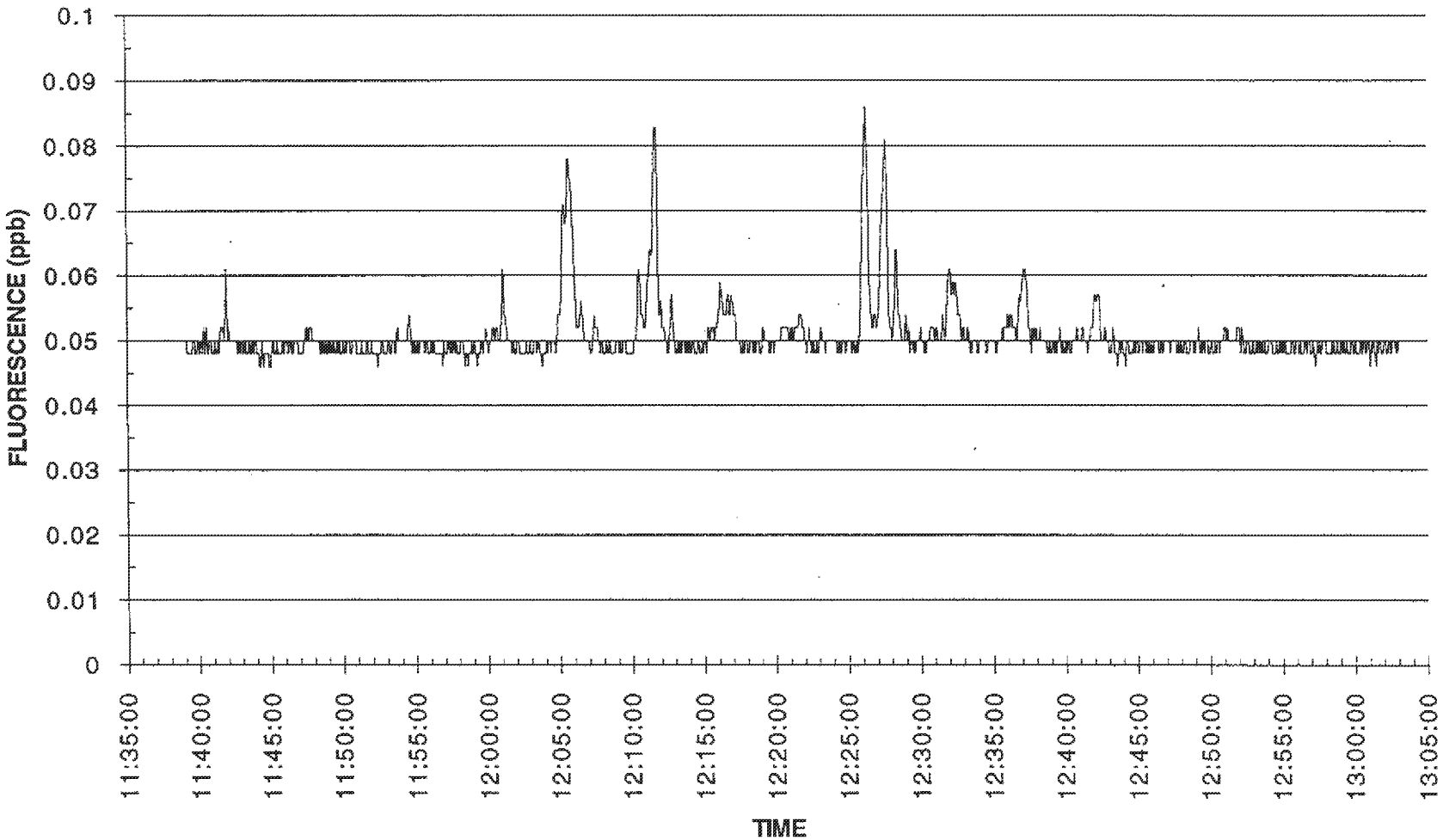
Date surveyed: 8/29/93




LINE 12
Date surveyed: 8/22/93
FLUORESCENCE (ppb)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
8:45:00
8:50:00
8:55:00
9:00:00
9:05:00
9:10:00
9:15:00
9:20:00
9:25:00
9:30:00
9:35:00
9:40:00
9:45:00
9:50:00
9:55:00
10:00:00
10:05:00
10:10:00
10:15:00
10:20:00
TIME

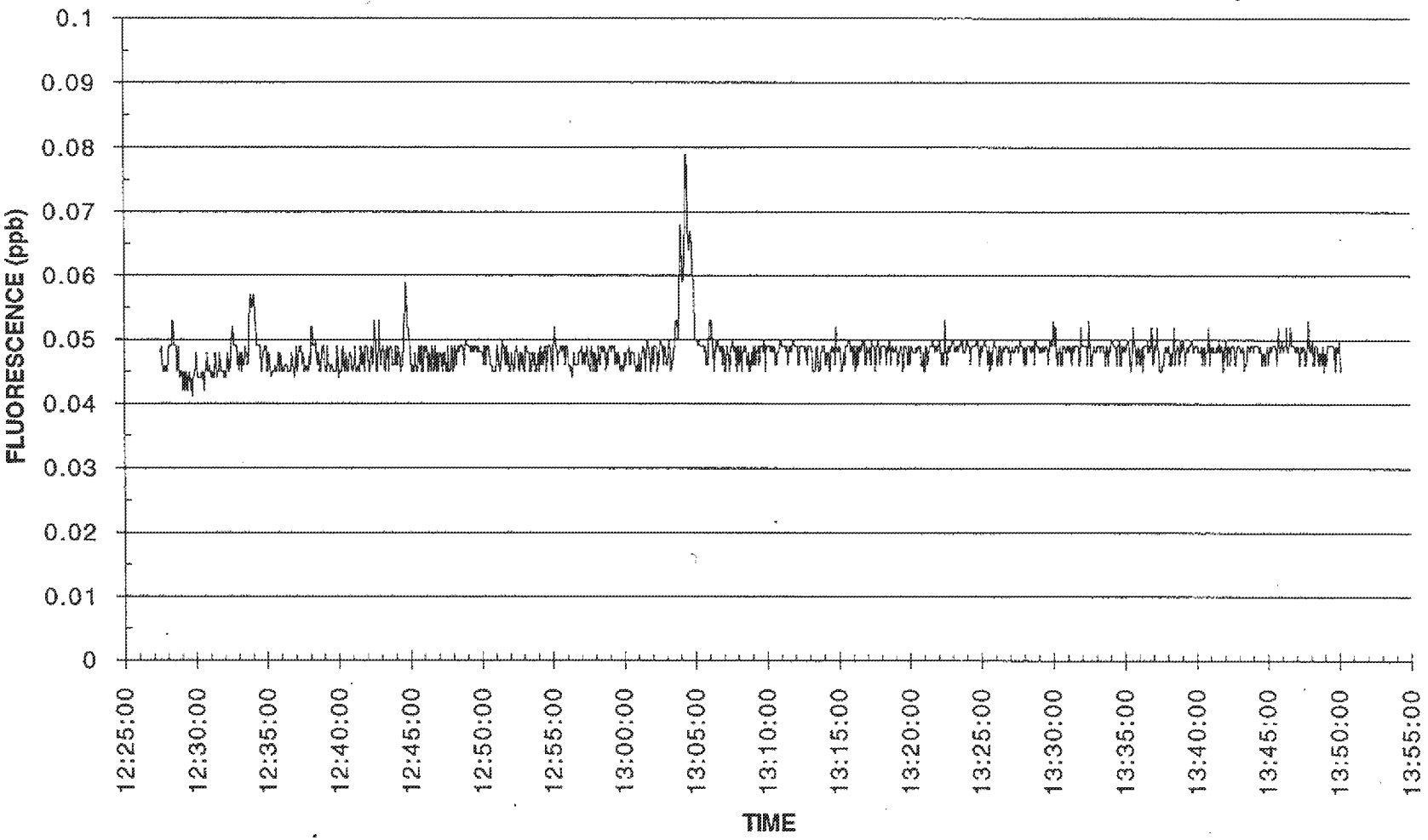
LINE 13A

Date surveyed: 8/29/93



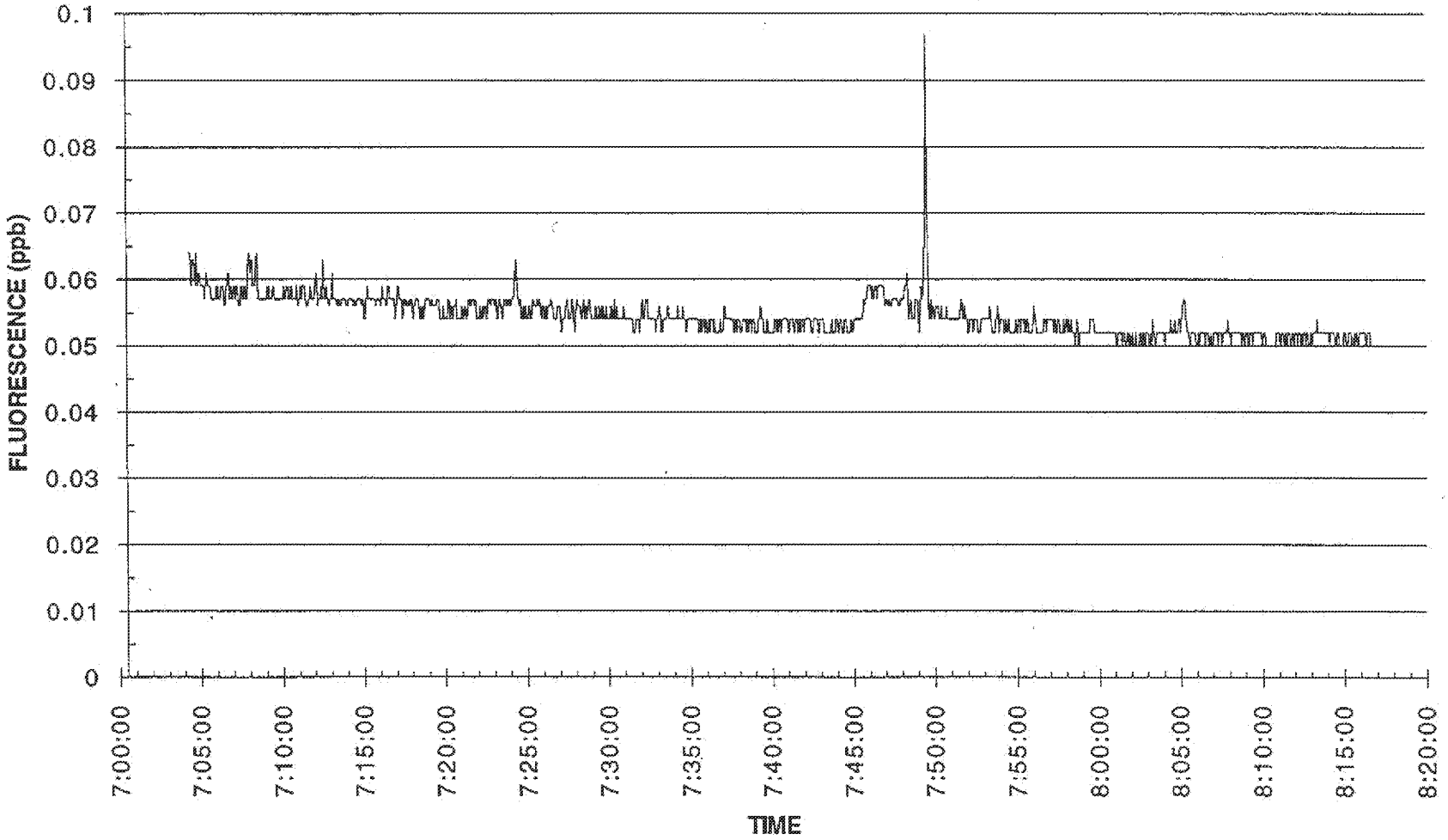
LINE 13

Date surveyed: 8/25/93



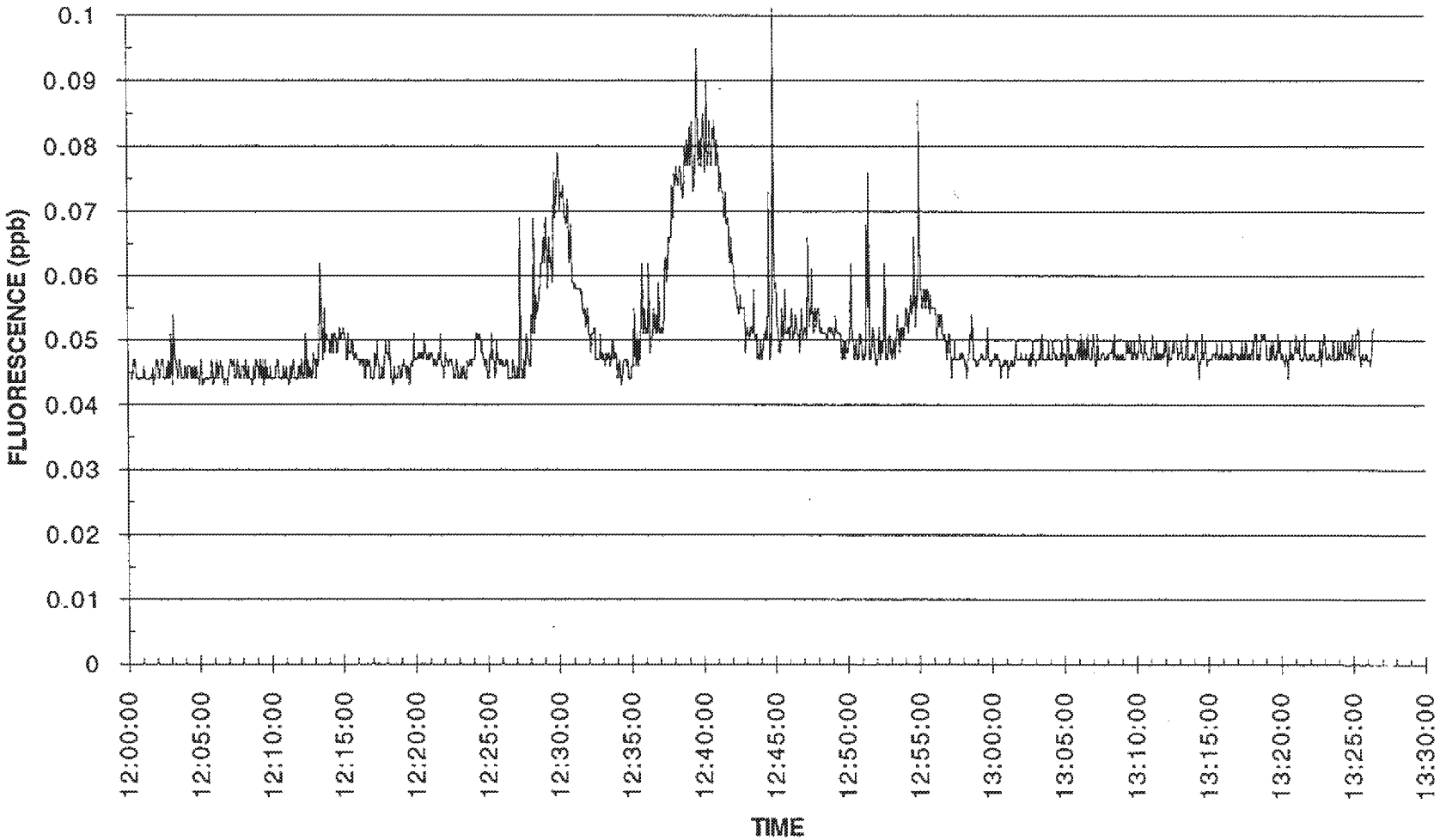
LINE 14A

Date surveyed: 8/30/93



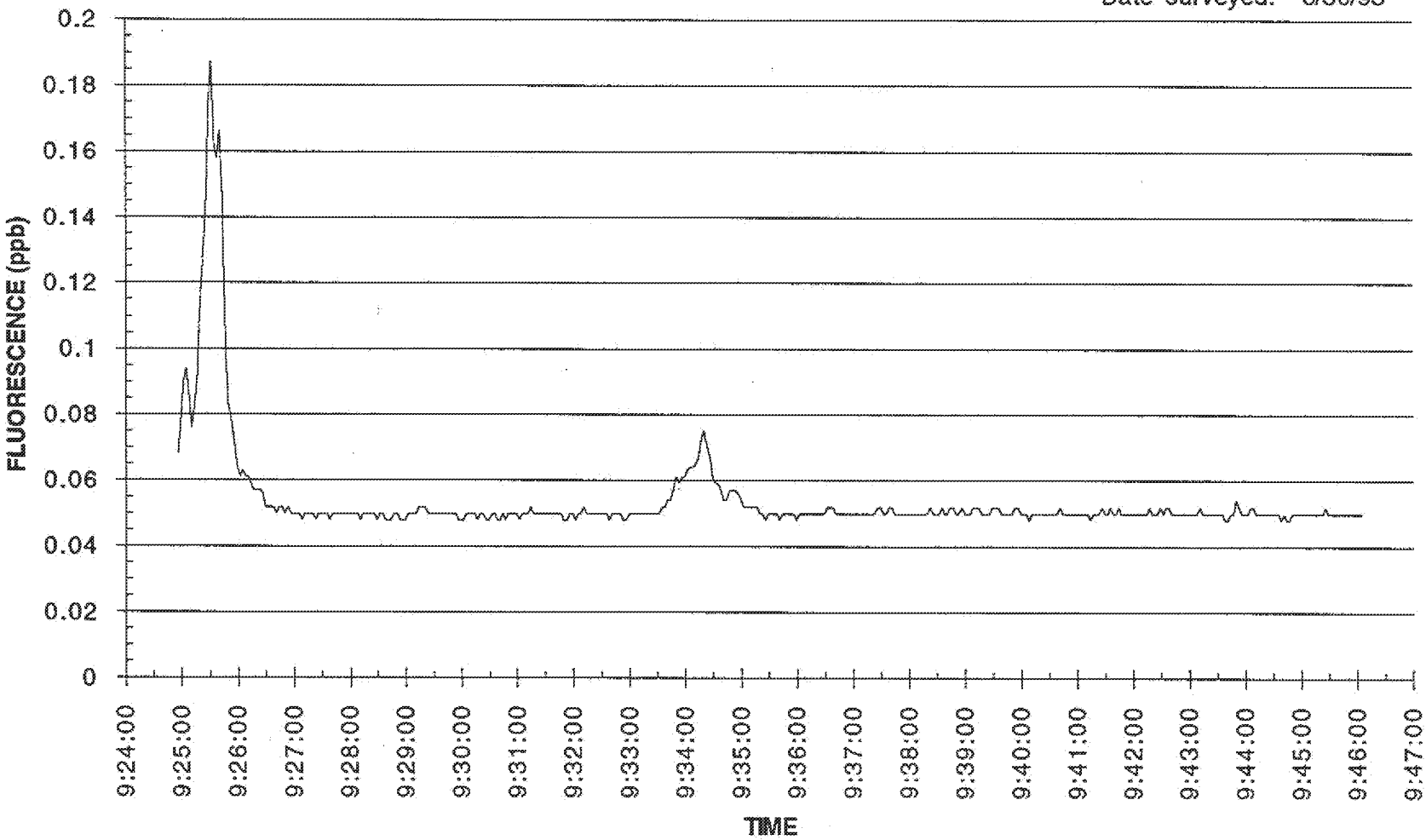
LINE 14

Date surveyed: 8/23/93



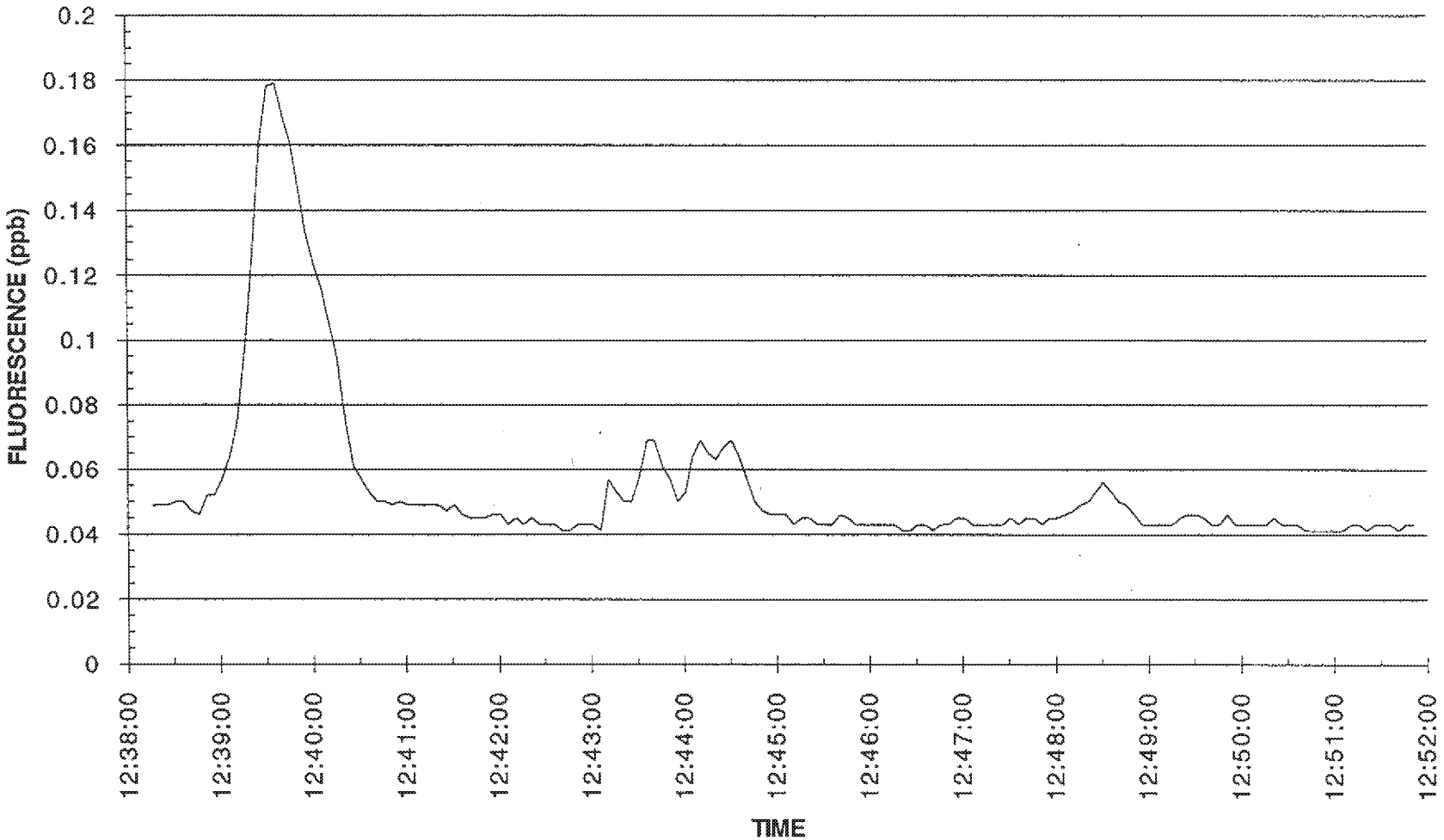
LINE 17A

Date surveyed: 8/30/93



LINE 17

Date surveyed: 8/24/93



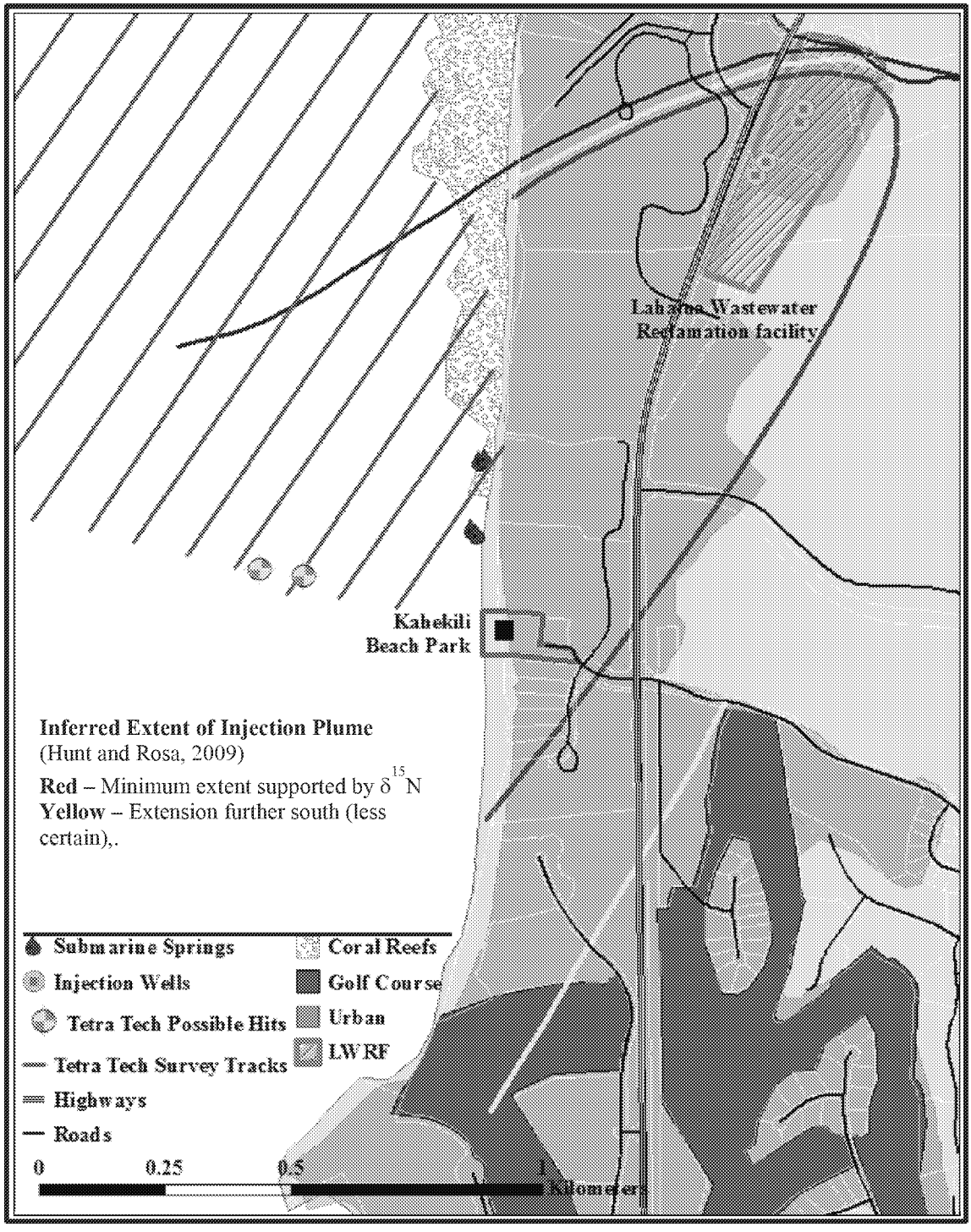


Figure 1-4: Map of the LWRF, submarine springs, and Tetra Tech (1994) ocean sampling tracts.

The location of the two occurrences of elevated fluorescence ("Hits") measured by Tetra Tech (1994) are shown. Also shown (Hunt and Rosa, 2009) are the likely minimum (red) and less certain maximum (yellow) spatial extents of the LWRF injectate plume, and inferred subsurface paleo-stream alluvium hydraulic barrier (blue).